CHAPTER 16 PRACTICE EXERCISES

SECTION I MULTIPLE CHOICE

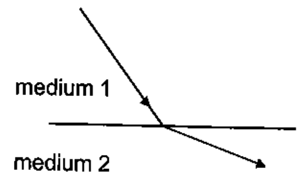

Figure 15

1. A light ray crosses an interface from medium 1 to medium 2 as shown in figure 15. Which of the following is true for the light in medium 2?

   (A) wave speed faster, wavelength shorter
   (B) wave speed faster, wavelength longer
   (C) wave speed slower, wavelength shorter
   (D) wave speed slower, wavelength longer
   (E) wave speed slower, wavelength unchanged

2. Eyeglasses make use of which property exhibited by light?

   (A) dispersion (B) reflection (C) refraction (D) interference (E) diffraction

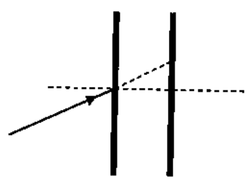

Figure 16

3. A light ray encounters a glass plate with parallel faces surrounded by air as shown in figure 16. The diagram that most accurately depicts the emerging ray is

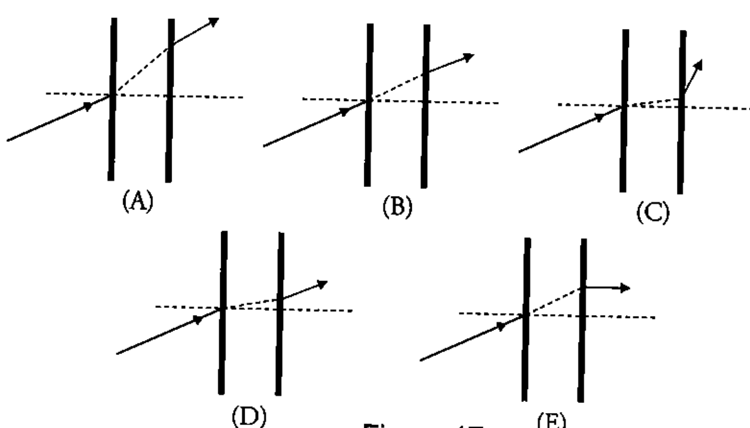

Figure 17

Figure 18

4. An arrow-shaped object is placed in front of a plane mirror as shown in figure 18. The image would look most like

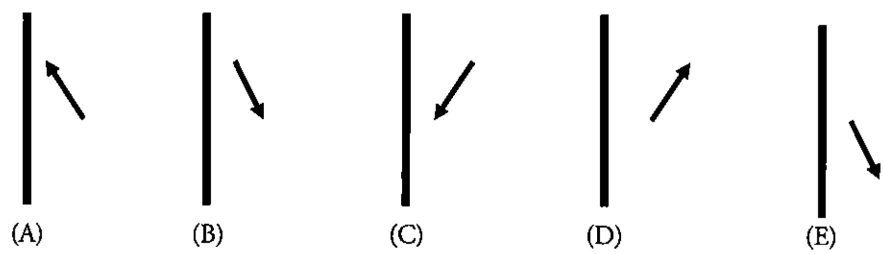

Figure 19

5. An illuminated arrow is placed 2 cm in front of a diverging lens with focal length − 6 cm. The image is

(A) real, inverted, smaller than the object
(B) virtual, inverted, larger than the object
(C) virtual, upright, larger than the object
(D) real, upright, larger than the object
(E) virtual, upright, smaller than the object

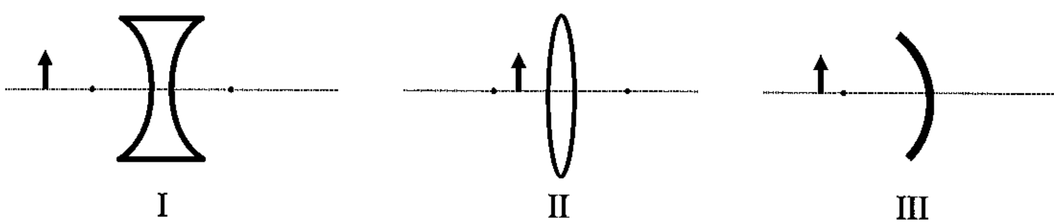

Figure 20

6. An object is placed in front of three different optical devices, two lenses and a mirror, with focal points as shown in figure 20. Which will produce a real image?

(A) I only (B) II only (C) III only (D) I and II (E) II and III

7. A concave mirror with radius of curvature 1.5 m is used to collect light from a distant source. The distance between the image formed and the mirror is closest to

(A) 0.75 m (B) 1 m (C) 1.5 m (D) 2 m (E) 3 m

8. A student sets up an optics experiment with a converging lens of focal length 10 cm. He places an illuminated arrow 2 cm high at 15 cm from the lens along the lens axis. The size of the image is most nearly

(A) 0.5 cm (B) 1 cm (C) 2 cm (D) 3.5 cm (E) 4 cm

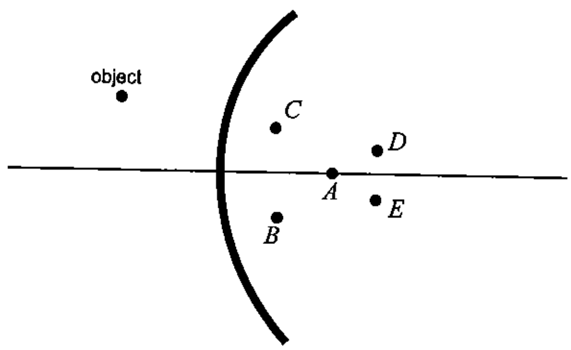

Figure 21

9. An object is placed in front of a concave mirror as shown in figure 21. The location of the image is closest to

(A) A (B) B (C) C (D) D (E) E

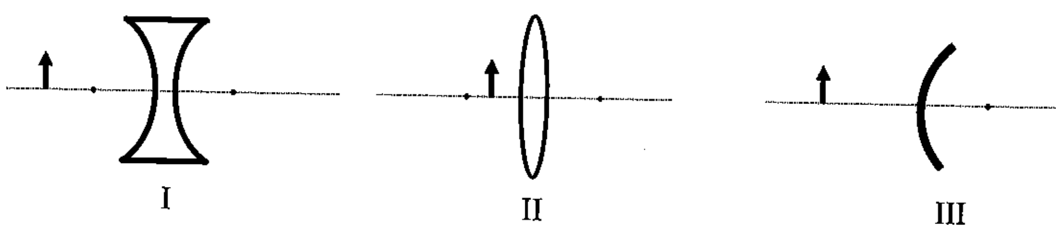

Figure 22

10. For which cases will the image of the arrow shown in figure 22 be virtual and smaller than the object?

(A) I only (B) II only (C) III only (D) I and II (E) I and III

CHAPTER 16

PRACTICE EXERCISES

SECTION II FREE RESPONSE

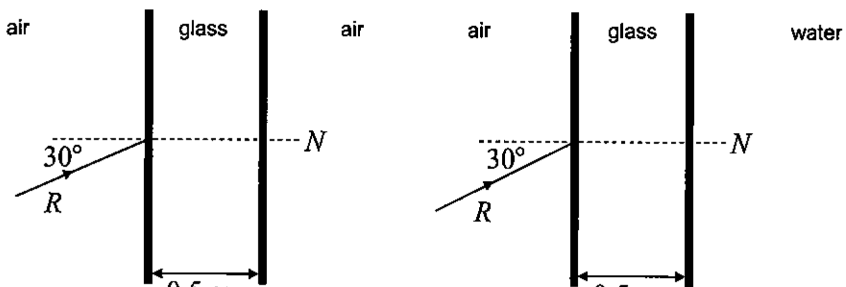

Figure 23

1. The figures above show an enlarged portion of the glass wall of a fish tank, currently empty so that air (n = 1) is on either side of the glass (n = 1.5). The glass is 0.5 cm thick. A ray R is incident on the glass at a 30° angle with the normal line as shown.
   (a) On the first figure, continue the ray, showing qualitatively what happens at the next interface.
   (b) At what distance above the normal line N will the transmitted ray emerge out of the glass?
   (c) Determine the incident angle at the second interface that will ensure total internal reflection. Could the initial ray R have its incident angle adjusted to make this happen? Explain.
   (d) Suppose the tank is filled with water (n = 1.33). On the second figure provided, continue the ray, showing qualitatively what happens at the glass-water interface.

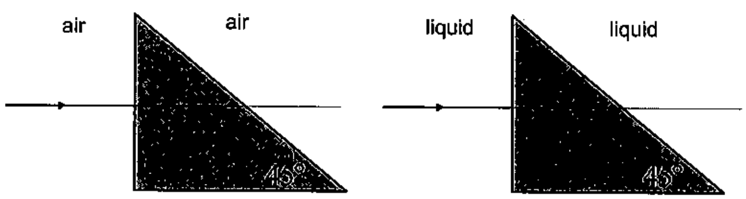

Figure 24

2. A ray of light of wavelength 680 nm (red) enters an isosceles right prism as shown in the figure above. The index of refraction for this wavelength is 1.22 in the prism. Assume air surrounds the prism.
   (a) On the first figure, continue the ray to the next interface and show the behavior qualitatively at this interface.
   (b) Find the wavelength of the light in the prism.
   (c) Determine the angle that the ray leaving the prism makes with the original direction of the ray, shown as a dotted line in the figure.
   (d) Violet light of wavelength (in air) 460 nm with an index of refraction 1.26 is added to the ray so that both colors are in the ray. Determine the angular separation of the two rays as they leave the prism.
   (e) The prism is now immersed in a transparent liquid with an index of refraction that is 1.50 for both colors. On the second figure, continue the ray and show the qualitative behavior at the second interface.

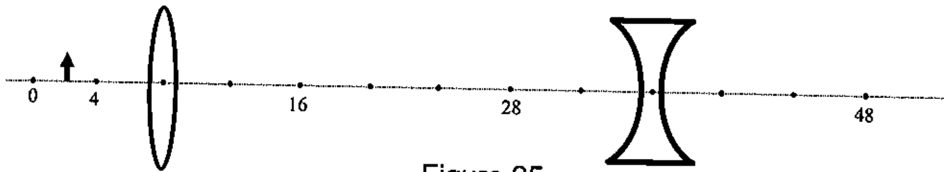

Figure 25

3. A converging lens with focal length 4 cm has an object placed 6 cm in front of it as pictured. A diverging lens with focal length − 8 cm is placed 28 cm behind the first lens.
   (a) Determine the position of the image formed by the first lens.
   (b) On the figure, draw the rays needed to display this image.
   (c) What is the magnification of this image?
   (d) Determine the position of the image formed by the second lens.
   (e) On the figure, sketch the rays needed to display this image.
   (f) Find the overall magnification of this lens system. What is the nature of the final image?

Answers and Explanations

MULTIPLE CHOICE

1. The answer is B. The ray is bending away from the normal line in medium 2, indicating that the index of refraction in medium 2 is less than that in medium 1. For concreteness, you could think of medium 1 as glass and medium 2 as air. The wave is moving faster with a longer wavelength.

2. The answer is C. Eyeglasses focus light with lenses, which focus by refraction.

3. The answer is D. At the first interface, it bends toward the normal, so the ray will exit below the dotted line extension of the original ray. Upon refraction, it will bend away from the normal just enough to be parallel to the original ray, because the incident angle at the second interface is the refracted angle at the first interface.

4. The answer is D. A plane mirror creates an upright virtual image with no magnification. You could draw two rays to check this. The object and image distance for each point on the arrow will then be equal.

5. The answer is E. A diverging lens (negative focal length) will always create an upright, virtual image in front of the object, as you can see by simple ray tracing. Since the image distance is smaller than the object distance, the image will be smaller as well.

6. The answer is C. A single concave lens produces only virtual images. An object placed inside the focal length of a convex lens will result in a virtual image. This eliminates I and II. An object outside the focal length of a concave mirror will produce an inverted, real image.

7. The answer is A. Distant objects will be imaged near the focal point since the rays are nearly parallel when they arrive at the mirror. The focal length of a spherical mirror is $\frac{1}{2}$ the radius of curvature.

8. The answer is E. Use the image equation to find the image distance, and then use the magnification equation.

$$\frac{1}{10} = \frac{1}{15} + \frac{1}{s_i} \qquad s_i = 30 \text{ cm}$$

$$m = -\frac{30}{15} = -2 \qquad \text{The size of the inverted image is 4 cm.}$$

9. The answer is C. A convex (diverging) mirror will produce upright, virtual images smaller than the object, as you can see with simple ray tracing, using two principle rays.

10. The answer is E. Diverging elements like I and III will always produce smaller virtual images. II will produce a virtual image, but it will be larger. This is basically a magnifying glass.

FREE RESPONSE

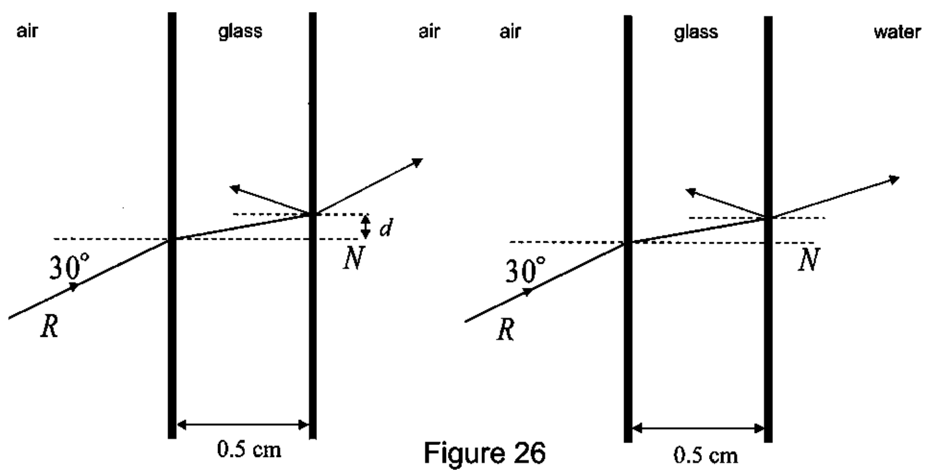

Figure 26

1. (a) The figure shows the reflected and refracted rays. You can find the refracted angle at the first interface from Snell's law.

$$1 \sin 30 = 1.5 \sin\theta_{R1} \quad \Rightarrow \theta_{R1} = 19.5°$$

Since the glass surfaces are parallel, this will become the incident angle of the second interface. Then you can use Snell's law to find the second refracted angle.

$$1.5 \sin\theta_{R1} = 1 \sin\theta_{R2} \quad \Rightarrow \theta_{R2} = 30°$$

The exiting ray is parallel to the original ray.

(b) From geometry, you have

$$\tan\theta_{R1} = \tan 19.5 = \frac{d}{0.5} \quad \Rightarrow d = 0.18 \text{ cm}$$

(c) For total internal reflection at the glass-air interface, you must have

$$1.5 \sin\theta_c = 1 \sin 90 \quad \Rightarrow \theta_c = 41.8°$$

The refracted beam exits at a limiting angle of 90° as the critical angle approaches. Since the exiting ray and the initial ray will be parallel, as shown in b, to get total internal reflection at the second interface would require a 90° incident angle at the first interface, indicating that the ray didn't actually enter the glass. You can get very close to total internal reflection at the second interface, but you'll never quite reach it.

(d) At the second interface, the reflection is the same. The ray that refracts into the water, however, won't bend away from the normal as much because the index of refraction doesn't change as much at a glass-water interface.

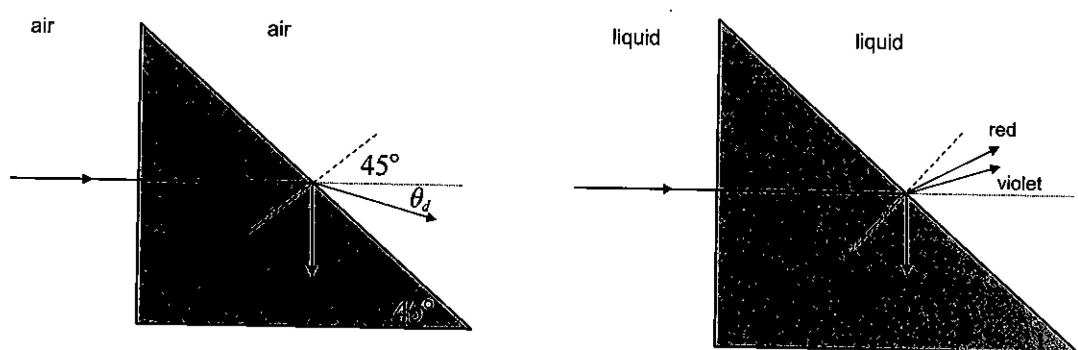

Figure 27

2. (a) The exiting ray bends away from the normal line. The reflected ray goes straight down because the incident and reflected angles are both 45°. Notice that the angle of refraction is 45° plus the deviation angle θ_d.

(b) The wavelength shortens in the slower medium by a factor of the index of refraction.

$$\lambda' = \frac{680}{1.22} = 557 \text{ nm}$$

(c) Use Snell's law.

$$1.22\ \sin 45 = 1 \sin\theta_R \quad \Rightarrow \theta_R = 59.6°$$

Then, $\theta_d = 14.6°$.

(d) Find the refracted angle for the violet ray and determine the difference in the two refraction angles.

$$1.26\ \sin 45 = 1\ \sin\theta_R' \quad \Rightarrow \theta_R' = 63.0°$$

The difference or angular separation is $63 - 59.6 = 3.4°$

(e) At the second interface, the reflections will be the same for both rays because the law of reflection is independent of wavelength. Since the rays are entering a medium that has a greater index of refraction, they will bend toward the normal line. The red ray experiences the greater deflection, since the change in refraction index is greater for it.

3. (a) Use the image equation.

$$\frac{1}{4} = \frac{1}{6} + \frac{1}{s_i} \qquad \Rightarrow s_i = 12 \text{ cm}$$

(b) Figure 28

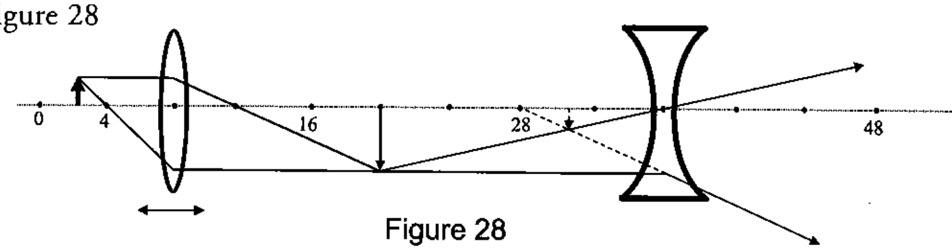

Figure 28

(c) $m_1 = -\frac{s_i}{s_o} = -\frac{12}{6} = -2$

(d) The image of the first lens will act as the object of the second lens. This makes the object distance 16 cm. Then you have

$$\frac{1}{-8} = \frac{1}{16} + \frac{1}{s_i} \qquad \Rightarrow s_i = -5.33 \text{ cm}$$

(e) See figure 28.

(f) The magnification of the second lens will be $m_2 = -\frac{-5.33}{16} = +\frac{1}{3}$. The overall magnification will be the product of the two separate values.

$$m = m_1 m_2 = \frac{-2}{3}$$

The image is virtual and inverted.